

**DEVICE FOR RECEIVING AND/OR EMITTING ELECTROMAGNETIC
WAVES WITH RADIATION DIVERSITY**

5 The present invention relates to a device for
receiving and/or transmitting electromagnetic waves
with radiation diversity which can be used in the field
of wireless transmissions, notably in the case of
transmissions in closed or semi-closed environments
10 such as domestic wireless networks, gymnasiums,
television studios, show venues or similar places, but
also in wireless communication systems requiring a
minimal size for the antenna system such as in mobile
telephones.

15 In the known high-bit-rate wireless
transmission systems, the signals transmitted by the
transmitter reach the receiver via a plurality of
different routes. When these are combined at the
receiver, the phase differences between the various
20 radio waves having followed pathways of different
lengths give rise to an interference figure which can
cause a tendency to fade or a significant degradation
of the signal. Moreover, the position of the tendency
to fade changes over time, depending on changes in the
25 environment, such as the presence of new objects or
passing people. This tendency to fade, caused by the
multiplicity of pathways, can lead to a significant
degradation both in the quality of the received signal
and in the performance of the system.

30 In order to fight against this tendency to
fade, the technique most often employed is a technique
known as spatial diversity. This technique consists
notably of using a pair of antennas having a wide
spatial coverage, such as two antennas of the "patch"
35 type, linked to a switching unit. The two antennas are
spaced out by a distance which must be greater than or
equal to $\lambda_0/2$, where λ_0 is the wavelength corresponding

to the operating frequency of the antenna. With this type of antenna, it can be shown that the probability of having both antennas in a fading condition simultaneously is very low. Moreover, the switching unit allows the branch connected to the antenna presenting the highest signal level to be selected by examining the received signal using a monitoring circuit. However, the main drawback with this solution is that it is relatively voluminous since it requires a minimum spacing between the radiating antennas in order to ensure an adequate decorrelation of the channel responses seen through each radiating element.

Various solutions have been proposed for reducing the size of the antenna system while still ensuring an adequate diversity. Some solutions have been the object of several patent applications filed in the name of THOMSON Multimedia Licensing S.A. They consist, notably, of using several antennas of the slot type supplied via line-slot transitions and comprising means allowing a diversity of radiation to be obtained, notably diodes allowing switching onto one or other of the antennas depending on the level of the received signal.

Furthermore, in the IEEE article, Vol. 49, No. 5 of May 2001, entitled "Diversity antenna for external mounting on wireless handsets", it has also been proposed, in the field of mobile telephones, to link a $\lambda/4$ slot with a monopole to produce a diversity radiation system. However, the proposed system is a relatively complex, three-dimensional structure.

The aim of the present invention is therefore to propose a new solution for a device for receiving and/or transmitting electromagnetic waves with radiation diversity having an extremely compact structure while still exhibiting radiation patterns with a very good complementarity. It also provides a device for receiving and/or transmitting

electromagnetic waves with radiation diversity having a relatively low cost of manufacture.

Consequently, the subject of the present invention is a device for receiving and/or transmitting
5 electromagnetic waves with radiation diversity, characterized in that it comprises, on a common substrate, at least one antenna of the slot type formed by a closed curve, electromagnetically coupled to a first supply line, and an antenna radiating parallel to
10 the substrate such as a monopole, a helix operating in transverse mode or similar, positioned inside the slot antenna and connected to a second supply line, said first and second supply lines being connected via a switching means to . means for exploiting the
15 electromagnetic waves.

The device for the reception and/or transmission of electromagnetic waves described above exploits the fact that antennas of the slot type formed by a closed curve, hereinafter referred to as slot
20 antennas, as well as antennas of the monopolar or helical type operating in transverse mode exhibit virtually omnidirectional radiation patterns with minima situated, respectively, in the plane of the substrate for the slot antenna and along the axis of
25 the monopole or helix for the other antenna. Thus, switching from one antenna to the other allows the channel response through the antenna to be modified and allows the system to thus benefit from a gain in diversity.

30 According to preferred embodiments, the first supply line is implemented in microstrip technology or in coplanar technology. Furthermore, the first supply line has a length between its end and the electromagnetic coupling point equal to $k\lambda_m/4$, where k
35 is an odd integer and λ_m the guided wavelength on the supply line at the central operating frequency with $\lambda_m = \lambda_0/\sqrt{\epsilon_{r_{eff}}}$, where λ_0 is the free-space wavelength and

ϵ_{eff} the effective permittivity of the line. The second supply line is implemented in microstrip technology or by a coaxial line. When the line is implemented in microstrip technology, a connection is made at the slot antenna between the part that is external and the part that is internal to the slot, this connection being formed, for example, by a conducting insert having a width equal to around two to three times the width of the line implemented in microstrip technology, so as not to interfere with the operation of the microstrip line providing the excitation. In addition, in order to minimize the interference within the slot of the slot antenna, owing to the presence of the conducting connection, this connection is situated in an electrical short-circuit plane for the slot which is therefore the plane where the microstrip line providing the excitation of the monopole or helical antenna crosses the slot antenna.

According to preferred embodiments, the slot antenna is formed by an annular slot of circular shape or formed by a closed curve of perimeter equal to $k'\lambda_s$ where k' is an integer and λ_s is the wavelength in the slot at the operating frequency and/or by a slot of polygonal shape such as a square or rectangle. According to another feature of the present invention, the device for receiving and/or transmitting electromagnetic waves with radiation diversity may comprise several slot antennas interlocking with one another so as to widen the operating band or to allow multiband applications.

Other features and advantages of the present invention will become apparent upon reading the description of various embodiments presented with reference to the appended drawings, in which:

- Figure 1 is a schematic perspective view of a first embodiment of the present invention,

- Figures 2 and 3 are respectively a cross-sectional and a top view of the first embodiment,

- Figures 4 and 5 show perspective views of the radiation patterns of the monopole and of the slot antennas, respectively, for a device according to Figures 1 to 3,

- Figure 6 shows a curve plotting the S parameters in dB as a function of frequency between the various "ports" for a device according to Figures 1 to 3,

- Figure 7 is a cross-sectional view of a second embodiment of the present invention,

- Figure 8 is an identical curve to that in Figure 6 for the second embodiment,

- Figures 9 and 10 show the radiation patterns of the slot and of the monopole antennas, for a device according to Figure 7.

In order to simplify the description, in the drawings the same elements carry the same reference numbers.

As shown in Figures 1 to 3, the device for receiving and/or transmitting electromagnetic waves consists essentially of a slot antenna 1 formed by a closed curve, more particularly an annular slot, and of an antenna 2 radiating parallel to the plane of the slot, namely a monopole in the embodiment shown. The monopole 2 is positioned at the center of the slot antenna 1. More specifically, as shown in Figures 2 and 3, the device of the present invention comprises a substrate made from dielectric material 3 whose top surface has been metallized. The annular slot 1 is fabricated by demetallization of the metallic layer 4 around a circle of diameter depending on the operating wavelength of the device, more particularly its perimeter is equal to $k'\lambda_s$ where λ_s is the wavelength in the slot at the operating frequency and k' is an integer.

Furthermore, a circular opening 5 of diameter D is provided at the center of the annular slot. This opening receives the monopole 2 in its central part which also passes through the substrate 3. An annular
5 metallic mounting disk 5 is provided on the lower face of the substrate 3 under the monopole 2. As shown more particularly in Figure 3, the annular slot 1 is excited, according to the method described by Knorr, by a microstrip line 6 connected to the port 1. This
10 microstrip line 6 is fabricated on the lower face of the substrate. Between its free end 6' and the electromagnetic coupling point with the slot 2, it has a length $L_m = k\lambda_m/4$, where λ_m is the wavelength on the line and k is an odd integer.

15 Similarly, in the embodiment shown, the monopole 2 is excited by a microstrip line 7.

As shown in Figure 3, in order to ensure continuity of the ground plane for the microstrip line 7 that excites the monopole 2, a connection is made
20 between the internal disk and the external ring forming the annular slot 1. This connection is made by means of a conducting insert 8 of width w that is large enough (width equal to around 2 to 3 times the width of the printed line providing the excitation) so as not to
25 interfere with the operation of the microstrip line providing the excitation. In order to minimize the interference at the annular slot from the presence of this metallic insert, the latter is located in a plane of electrical short-circuit for the slot, which will
30 therefore be the plane where the line providing the excitation of the monopole crosses the annular slot.

As presented in Figures 4 and 5, the annular slot 1 and the monopole 2 exhibit radiation patterns that are virtually omnidirectional and relatively
35 complementary in that the minima m are situated, for the annular slot, in the plane of the substrate (in this case, along the axis ox) and, for the monopole,

along the axis of the latter (in this case the axis
oz). Thus, switching from one port to the other (by
means of a switching device that is well known to those
skilled in the art, such as a switch, positioned
5 between the supply lines 6 and 7 and the part for
processing the signal, controlled by a control signal
such as the signal level, the signal-to-noise ratio or
similar) allows the channel response through the
antenna to be modified and allows the system to thus
10 benefit from a gain in diversity. Accordingly, if the
dominant received signal arrives along the ox axis, for
example, which would imply that a weak signal is
received through the access connected to the slot, by
switching to the access connected to the monopole, it
15 is very probable that a signal with a substantial level
will be received given that the direction ox
corresponds to a maximum in the monopole pattern. A
symmetric argument can be applied to the case where the
dominant signal arrives along the oz axis, for example
20 in the case of a multistage communication.

In this case, the coupling between the annular
slot 1 and the monopole 2 remains weak given:

i) the complementarity of the
radiation patterns (the directions of the
25 maxima of one are in the direction of the
minima of the other);

ii) the orthogonality of the fields
emitted by the slot and the monopole antennas.

Minimal mutual interference can thus be
30 expected between the two radiating elements even though
they occupy almost the same physical space.

In order to ensure correct operation of a
transmission/reception device such as described above,
the dimensions of the latter have been completely
35 chosen for operation at the central frequency of around
5.8 GHz then simulated using the HFSS simulation
package from Ansoft. With reference to the schematic

drawings in Figure 1 to 3, the antenna system formed by an annular slot 1 and a monopole 2 has the following dimensions:

- $R_{int} = 6.4$ mm (internal radius of the slot)
- 5 • $R_{ext} = 6.8$ mm (external radius of the slot)
- $W_s = 0.4$ mm (width of the slot, $W_s = R_{ext} - R_{int}$)
- $W_{m1} = 0.3$ mm (width of the microstrip line supplying the slot)
- 10 • $l_{m1} = 8.25$ mm (length of the microstrip line supplying the slot between the port 1 and the line/slot transition)
- $l_{m1}' = 8.25$ mm (length of the microstrip line supplying the slot between the line/slot transition and the end of the line in open circuit)
- 15 • $D = 2$ mm (diameter of the demetallization at the center of the slot)
- $L = 13.21$ mm (length of the monopole)
- $\square = 30$ mm (diameter of the ground plane)
- 20 • $\square_{monopole} = 1$ mm (diameter of the metallic wire forming the monopole)
- $W_{m2} = 0.2$ mm (width of the microstrip line supplying the monopole)
- $l_{m2} = 8.4$ mm (length of the microstrip line supplying the monopole between the port 2 and the line/slot transition)
- 25 • $l_{m2}' = 8.8$ mm
- insert 1.2 mm long (or 3% of the slot length)
- a metallic disk of diameter 2 mm is placed
- 30 under the monopole (this facilitates the soldering of the monopole to its supply line)

The substrate used is made of Rogers 4003 with relative permittivity $\epsilon_r = 3.38$ and thickness $h = 0.81$ mm.

35 Figure 6 shows the simulation results of the reflection coefficients at the input of the lines supplying the annular slot (S11) and the monopole

(S22) as well as the coupling coefficient (S21) between the two ports 1 and 2. A good matching of the two antennas can be observed as well as an isolation better than 19 dB between the two accesses despite the
5 extreme proximity of the two radiating elements, namely the slot 1 and the monopole 2.

In this case, the radiation patterns obtained at the monopole and annular slot access, respectively, are those shown in Figures 4 and 5. Despite a slight
10 distortion of the monopole pattern, it can be observed that the antenna system operates as desired, in other words therefore with virtually omnidirectional, complementary patterns with the minima along the oz axis for the monopole and along the ox axis for the
15 annular slot.

According to a variant, shown in Figure 7, the monopole is excited by a coaxial line connected at the port 2. In this variant 2, the excitation of the monopole is on the substrate ground plane 9 side. In
20 this case, the ground plane 9 is formed on the lower surface of the substrate 3. The antenna consisting of the annular slot 1 is formed in this ground plane. The supply line formed by a microstrip line 6 is now implemented on the upper surface of the substrate, the
25 excitation taking place as in the previous embodiment. Simulations specific to this variant have been carried out using the HFSS package from Ansoft, on a particular implementation dimensioned as follows:

- $R_{int} = 6.4$ mm (internal radius of the slot)
- 30 • $R_{ext} = 6.8$ mm (external radius of the slot)
- $W_s = 0.4$ mm (width of the slot, $W_s = R_{ext} - R_{int}$)
- $W_{m1} = 0.3$ mm (width of the microstrip line supplying the slot)
- 35 • $l_{m1} = 8.25$ mm (length of the microstrip line supplying the slot between the port 1 and the line/slot transition)

- $l_{m1}' = 8.25$ mm (length of the microstrip line supplying the slot between the line/slot transition and the end of the line in open circuit)

- $D = 2$ mm (diameter of the demetallization at the center of the slot)

- $L = 12.4$ mm (length of the monopole)

- $\square = 30$ mm (diameter of the ground plane)

- $\square_{\text{monopole}} = 1$ mm (diameter of the metallic wire forming the monopole)

The substrate used is made of Rogers 4003 with relative permittivity $\epsilon_r = 3.38$ and thickness $h = 0.81$ mm.

The matching at the two accesses as well as the isolation between the two ports are shown in Figure 8. The curve S_{21} shows a good isolation while the curves S_{11} and S_{22} show a good matching at the operating frequency of 5.8 GHz. Figures 9 and 10 present the radiation patterns, respectively at the slot and monopole access, of the device for the transmission and/or reception of electromagnetic waves described above. It can be observed that the excitation of the monopole by coaxial line, which has the advantage of avoiding the crossing of the excitation line of the monopole and the slot antenna, presents a better isolation (isolation greater than 22 dB) than in the case of the excitation by microstrip line and the monopole pattern is no longer distorted. This advantage is gained at the expense of an increase in complexity of the antenna structure (slot and monopole access on opposite faces of the substrate and of different types: coaxial line and microstrip line).

Further modifications may be included such as the use of a helix operating in the transverse mode in place of the monopole, the use of a double or multiple slot in order to widen the band or for multiband applications, tangential supply of the slot in place of a Knorr-type supply, and the deformation of the

annular slot to further reduce its size, where it could also take the form of a square, a rectangle or other polygon while still remaining within the scope of the definition given above. Similarly, the monopole or helix may be replaced by antennas of the same type which can be placed at the center of the slot antenna and which radiate in a direction parallel to the substrate. The supply line of the slot antenna can be implemented as a line in microstrip technology or in coplanar technology. In addition, the slot antenna may have means, such as notches in the case of an annular slot, that allow it to operate in cross-polarization mode.